OUTPUTS

PART A: IN-LAB

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CIFAR-10 CNN TRAINING PIPELINE - PART A
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SHAPE VERIFICATION
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Input shape: torch.Size([1, 3, 32, 32])
After conv1 + bn1 + relu: torch.Size([1, 32, 32, 32])
After pool1: torch.Size([1, 32, 16, 16])
After conv2 + bn2 + relu: torch.Size([1, 64, 16, 16])
After pool2: torch.Size([1, 64, 8, 8])
After conv3 + bn3 + relu: torch.Size([1, 128, 8, 8])
After global avg pool: torch.Size([1, 128, 1, 1])
After flatten: torch.Size([1, 128])
Output shape: torch.Size([1, 10])
All shapes look correct!
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SANITY CHECK: Overfitting to 128 samples
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Epoch 10/100 - Loss: 1.7042 - Acc: 42.19%
Epoch 20/100 - Loss: 1.4209 - Acc: 56.25%
Epoch 30/100 - Loss: 1.1631 - Acc: 65.62%
Epoch 40/100 - Loss: 0.9114 - Acc: 79.69%
Epoch 50/100 - Loss: 0.6816 - Acc: 91.41%
Epoch 60/100 - Loss: 0.4951 - Acc: 97.66%
Epoch 70/100 - Loss: 0.3406 - Acc: 97.66%
Epoch 80/100 - Loss: 0.2016 - Acc: 100.00%
Epoch 90/100 - Loss: 0.1366 - Acc: 100.00%
Epoch 100/100 - Loss: 0.1025 - Acc: 100.00%
PASS: Model can overfit (accuracy > 95%)
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Initializing fresh model for full training...
Initial performance (before training):
Validation set: Avg. loss: 2.3004, Accuracy: 529/5000 (10.58%)


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Training for 10 epochs with LR=0.001
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Train Epoch: 1 [0/45000 (0%)]Loss: 2.313192
Train Epoch: 1 [12800/45000 (28%)]  Loss: 1.686781
Train Epoch: 1 [25600/45000 (57%)]  Loss: 1.431423
Train Epoch: 1 [38400/45000 (85%)]  Loss: 1.451987
Training set: Avg. loss: 1.3617, Accuracy: 23094/45000 (51.32%)
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Validation set: Avg. loss: 1.3652, Accuracy: 2575/5000 (51.50%)

Train Epoch: 2 [0/45000 (0%)]Loss: 1.367244
Train Epoch: 2 [12800/45000 (28%)]  Loss: 1.301166
Train Epoch: 2 [25600/45000 (57%)]  Loss: 1.296062
Train Epoch: 2 [38400/45000 (85%)]  Loss: 1.213425
Training set: Avg. loss: 1.2504, Accuracy: 24873/45000 (55.27%)

Validation set: Avg. loss: 1.2697, Accuracy: 2750/5000 (55.00%)

Train Epoch: 3 [0/45000 (0%)]Loss: 1.186542
Train Epoch: 3 [12800/45000 (28%)]  Loss: 1.152416
Train Epoch: 3 [25600/45000 (57%)]  Loss: 1.154126
Train Epoch: 3 [38400/45000 (85%)]  Loss: 1.114000
Training set: Avg. loss: 1.0984, Accuracy: 27206/45000 (60.46%)

Validation set: Avg. loss: 1.1120, Accuracy: 3026/5000 (60.52%)

Train Epoch: 4 [0/45000 (0%)]Loss: 1.141376
Train Epoch: 4 [12800/45000 (28%)]  Loss: 1.067182
Train Epoch: 4 [25600/45000 (57%)]  Loss: 1.062999
Train Epoch: 4 [38400/45000 (85%)]  Loss: 1.056037
Training set: Avg. loss: 1.0552, Accuracy: 27799/45000 (61.78%)

Validation set: Avg. loss: 1.0748, Accuracy: 3047/5000 (60.94%)

Train Epoch: 5 [0/45000 (0%)]Loss: 0.961330
Train Epoch: 5 [12800/45000 (28%)]  Loss: 1.077197
Train Epoch: 5 [25600/45000 (57%)]  Loss: 0.989892
Train Epoch: 5 [38400/45000 (85%)]  Loss: 0.985753
Training set: Avg. loss: 1.1550, Accuracy: 26640/45000 (59.20%)

Validation set: Avg. loss: 1.2137, Accuracy: 2856/5000 (57.12%)

Train Epoch: 6 [0/45000 (0%)]Loss: 1.161983
Train Epoch: 6 [12800/45000 (28%)]  Loss: 1.004312
Train Epoch: 6 [25600/45000 (57%)]  Loss: 1.028576
Train Epoch: 6 [38400/45000 (85%)]  Loss: 1.041875
Training set: Avg. loss: 1.0564, Accuracy: 28080/45000 (62.40%)

Validation set: Avg. loss: 1.1137, Accuracy: 3009/5000 (60.18%)

Train Epoch: 7 [0/45000 (0%)]Loss: 1.003755
Train Epoch: 7 [12800/45000 (28%)]  Loss: 0.975794
Train Epoch: 7 [25600/45000 (57%)]  Loss: 0.978930
Train Epoch: 7 [38400/45000 (85%)]  Loss: 0.986761
Training set: Avg. loss: 1.0286, Accuracy: 28818/45000 (64.04%)

Validation set: Avg. loss: 1.0767, Accuracy: 3099/5000 (61.98%)

Train Epoch: 8 [0/45000 (0%)]Loss: 0.889824
Train Epoch: 8 [12800/45000 (28%)]  Loss: 0.862486
Train Epoch: 8 [25600/45000 (57%)]  Loss: 0.972867
Train Epoch: 8 [38400/45000 (85%)]  Loss: 0.984135
Training set: Avg. loss: 0.9761, Accuracy: 29672/45000 (65.94%)

Validation set: Avg. loss: 1.0323, Accuracy: 3186/5000 (63.72%)

Train Epoch: 9 [0/45000 (0%)]Loss: 1.132221
Train Epoch: 9 [12800/45000 (28%)]  Loss: 0.999111
Train Epoch: 9 [25600/45000 (57%)]  Loss: 0.977644
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Train Epoch: 9 [38400/45000 (85%)]  Loss: 0.906519
Training set: Avg. loss: 0.8964, Accuracy: 30703/45000 (68.23%)

Validation set: Avg. loss: 0.9536, Accuracy: 3347/5000 (66.94%)

Train Epoch: 10 [0/45000 (0%)]       Loss: 0.960716
Train Epoch: 10 [12800/45000 (28%)] Loss: 0.920083
Train Epoch: 10 [25600/45000 (57%)] Loss: 0.979025
Train Epoch: 10 [38400/45000 (85%)] Loss: 0.896000
Training set: Avg. loss: 0.9463, Accuracy: 29902/45000 (66.45%)

Validation set: Avg. loss: 1.0121, Accuracy: 3242/5000 (64.84%)

Test set: Avg. loss: 1.0165, Accuracy: 6373/10000 (63.73%)
```
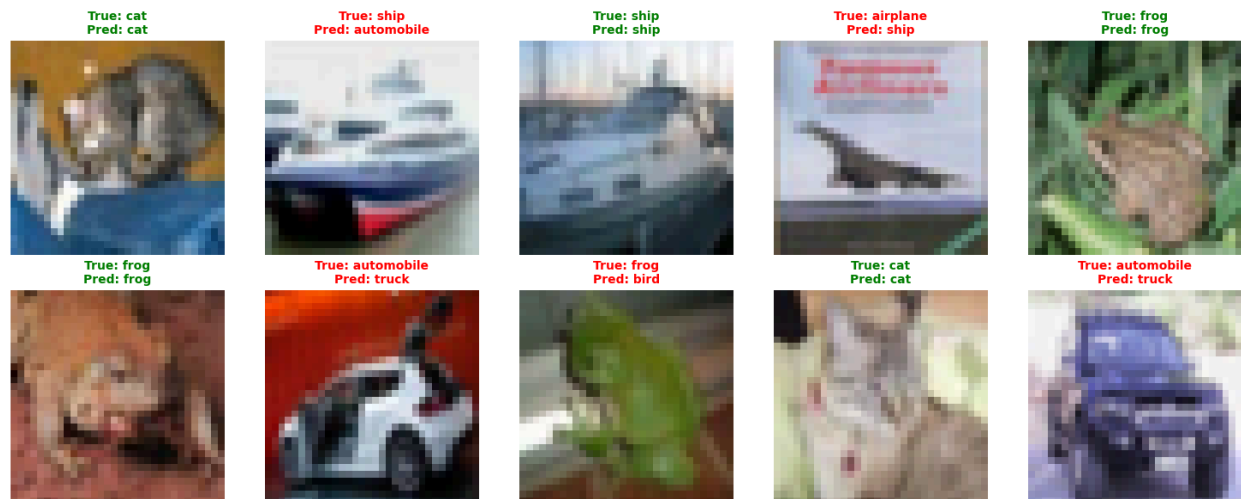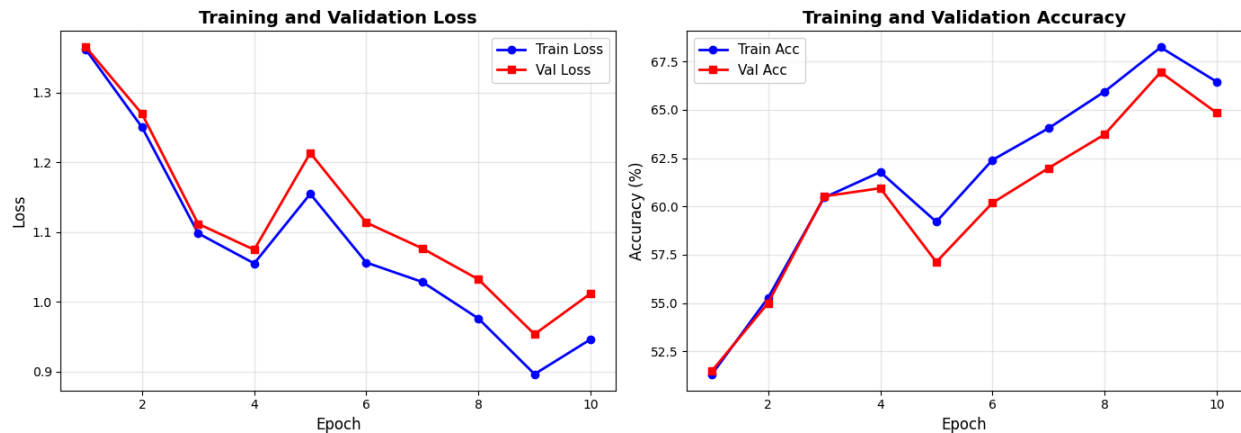

PART B: TAKE HOME

B.1 and B.2

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================================================================
CIFAR-10 CNN TRAINING PIPELINE - PART B (FULL TRAINING)
================================================================


Initial performance (before training):
Validation set: Avg. loss: 0.8966, Accuracy: 3442/5000 (68.84%)



================================================================
Starting Training - Part B
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Train Epoch: 1 [0/45000 (0%)]     Loss: 0.753535     LR: 0.000933
Train Epoch: 1 [12800/45000 (28%)]      Loss: 0.730809      LR: 0.000933
Train Epoch: 1 [25600/45000 (57%)]      Loss: 0.919621      LR: 0.000933
Train Epoch: 1 [38400/45000 (85%)]      Loss: 0.803493      LR: 0.000933
Validation set: Avg. loss: 0.8457, Accuracy: 3539/5000 (70.78%)

Epoch 1/30 completed in 31.00s
Train Loss: 0.7818 - Train Acc: 73.26%
Val Loss: 0.8457 - Val Acc: 70.78%
Best Val Acc: 70.78% (Epoch 1)
Learning Rate: 0.000905
----------------------------------------------------------------------


Train Epoch: 2 [0/45000 (0%)]     Loss: 0.646619     LR: 0.000905
Train Epoch: 2 [12800/45000 (28%)]      Loss: 0.625954      LR: 0.000905
Train Epoch: 2 [25600/45000 (57%)]      Loss: 0.666794      LR: 0.000905
Train Epoch: 2 [38400/45000 (85%)]      Loss: 0.731838      LR: 0.000905
Validation set: Avg. loss: 0.7903, Accuracy: 3658/5000 (73.16%)

Epoch 2/30 completed in 31.28s
Train Loss: 0.7332 - Train Acc: 75.19%
Val Loss: 0.7903 - Val Acc: 73.16%
Best Val Acc: 73.16% (Epoch 2)
Learning Rate: 0.000872
----------------------------------------------------------------------


Train Epoch: 3 [0/45000 (0%)]     Loss: 0.792497     LR: 0.000872
Train Epoch: 3 [12800/45000 (28%)]      Loss: 0.603221      LR: 0.000872
Train Epoch: 3 [25600/45000 (57%)]      Loss: 0.693238      LR: 0.000872
Train Epoch: 3 [38400/45000 (85%)]      Loss: 0.510798      LR: 0.000872
Validation set: Avg. loss: 0.7036, Accuracy: 3782/5000 (75.64%)

Epoch 3/30 completed in 29.95s
Train Loss: 0.6975 - Train Acc: 76.40%
Val Loss: 0.7036 - Val Acc: 75.64%
Best Val Acc: 75.64% (Epoch 3)
Learning Rate: 0.000835
----------------------------------------------------------------------


Train Epoch: 4 [0/45000 (0%)]     Loss: 0.560138     LR: 0.000835
Train Epoch: 4 [12800/45000 (28%)]      Loss: 0.580369      LR: 0.000835
Train Epoch: 4 [25600/45000 (57%)]      Loss: 0.574376      LR: 0.000835
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Train Epoch: 4 [38400/45000 (85%)]        Loss: 0.744597        LR: 0.000835
Validation set: Avg. loss: 0.6706, Accuracy: 3852/5000 (77.04%)

Epoch 4/30 completed in 31.20s
Train Loss: 0.6647 - Train Acc: 77.46%
Val Loss: 0.6706 - Val Acc: 77.04%
Best Val Acc: 77.04% (Epoch 4)
Learning Rate: 0.000794
------------------------------------------------------------------------

Train Epoch: 5 [0/45000 (0%)]    Loss: 0.495997     LR: 0.000794
Train Epoch: 5 [12800/45000 (28%)]        Loss: 0.484463        LR: 0.000794
Train Epoch: 5 [25600/45000 (57%)]        Loss: 0.684339        LR: 0.000794
Train Epoch: 5 [38400/45000 (85%)]        Loss: 0.587041        LR: 0.000794
Validation set: Avg. loss: 0.6628, Accuracy: 3858/5000 (77.16%)

Epoch 5/30 completed in 30.03s
Train Loss: 0.6363 - Train Acc: 78.50%
Val Loss: 0.6628 - Val Acc: 77.16%
Best Val Acc: 77.16% (Epoch 5)
Learning Rate: 0.000750
------------------------------------------------------------------------

Train Epoch: 6 [0/45000 (0%)]    Loss: 0.502344     LR: 0.000750
Train Epoch: 6 [12800/45000 (28%)]        Loss: 0.739168        LR: 0.000750
Train Epoch: 6 [25600/45000 (57%)]        Loss: 0.676424        LR: 0.000750
Train Epoch: 6 [38400/45000 (85%)]        Loss: 0.589789        LR: 0.000750
Validation set: Avg. loss: 0.6571, Accuracy: 3868/5000 (77.36%)

Epoch 6/30 completed in 30.09s
Train Loss: 0.6066 - Train Acc: 79.70%
Val Loss: 0.6571 - Val Acc: 77.36%
Best Val Acc: 77.36% (Epoch 6)
Learning Rate: 0.000704
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Train Epoch: 7 [0/45000 (0%)]    Loss: 0.586095     LR: 0.000704
Train Epoch: 7 [12800/45000 (28%)]        Loss: 0.591142        LR: 0.000704
Train Epoch: 7 [25600/45000 (57%)]        Loss: 0.548062        LR: 0.000704
Train Epoch: 7 [38400/45000 (85%)]        Loss: 0.542784        LR: 0.000704
Validation set: Avg. loss: 0.6229, Accuracy: 3960/5000 (79.20%)

Epoch 7/30 completed in 30.71s
Train Loss: 0.5870 - Train Acc: 80.35%
Val Loss: 0.6229 - Val Acc: 79.20%
Best Val Acc: 79.20% (Epoch 7)
Learning Rate: 0.000655
------------------------------------------------------------------------

Train Epoch: 8 [0/45000 (0%)]    Loss: 0.567645     LR: 0.000655
Train Epoch: 8 [12800/45000 (28%)]        Loss: 0.592398        LR: 0.000655
Train Epoch: 8 [25600/45000 (57%)]        Loss: 0.600263        LR: 0.000655
Train Epoch: 8 [38400/45000 (85%)]        Loss: 0.530157        LR: 0.000655
Validation set: Avg. loss: 0.5969, Accuracy: 3974/5000 (79.48%)
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Epoch 8/30 completed in 30.99s
Train Loss: 0.5634 - Train Acc: 81.04%
Val Loss: 0.5969 - Val Acc: 79.48%
Best Val Acc: 79.48% (Epoch 8)
Learning Rate: 0.000604
----------------------------------------------------------------------

Train Epoch: 9 [0/45000 (0%)]    Loss: 0.389653      LR: 0.000604
Train Epoch: 9 [12800/45000 (28%)]    Loss: 0.643795     LR: 0.000604
Train Epoch: 9 [25600/45000 (57%)]    Loss: 0.473434     LR: 0.000604
Train Epoch: 9 [38400/45000 (85%)]    Loss: 0.449701     LR: 0.000604
Validation set: Avg. loss: 0.6101, Accuracy: 3969/5000 (79.38%)

Epoch 9/30 completed in 30.17s
Train Loss: 0.5394 - Train Acc: 81.88%
Val Loss: 0.6101 - Val Acc: 79.38%
Best Val Acc: 79.48% (Epoch 8)
Learning Rate: 0.000553
----------------------------------------------------------------------

Train Epoch: 10 [0/45000 (0%)]    Loss: 0.602436      LR: 0.000553
Train Epoch: 10 [12800/45000 (28%)]    Loss: 0.410812     LR: 0.000553
Train Epoch: 10 [25600/45000 (57%)]    Loss: 0.549316     LR: 0.000553
Train Epoch: 10 [38400/45000 (85%)]    Loss: 0.496926     LR: 0.000553
Validation set: Avg. loss: 0.5896, Accuracy: 4018/5000 (80.36%)

Epoch 10/30 completed in 30.69s
Train Loss: 0.5267 - Train Acc: 82.30%
Val Loss: 0.5896 - Val Acc: 80.36%
Best Val Acc: 80.36% (Epoch 10)
Learning Rate: 0.000501
----------------------------------------------------------------------

Train Epoch: 11 [0/45000 (0%)]    Loss: 0.480802      LR: 0.000501
Train Epoch: 11 [12800/45000 (28%)]    Loss: 0.532095     LR: 0.000501
Train Epoch: 11 [25600/45000 (57%)]    Loss: 0.492915     LR: 0.000501
Train Epoch: 11 [38400/45000 (85%)]    Loss: 0.487581     LR: 0.000501
Validation set: Avg. loss: 0.5652, Accuracy: 4033/5000 (80.66%)

Epoch 11/30 completed in 29.97s
Train Loss: 0.5083 - Train Acc: 83.09%
Val Loss: 0.5652 - Val Acc: 80.66%
Best Val Acc: 80.66% (Epoch 11)
Learning Rate: 0.000448
----------------------------------------------------------------------

Train Epoch: 12 [0/45000 (0%)]    Loss: 0.481501      LR: 0.000448
Train Epoch: 12 [12800/45000 (28%)]    Loss: 0.430359     LR: 0.000448
Train Epoch: 12 [25600/45000 (57%)]    Loss: 0.623641     LR: 0.000448
Train Epoch: 12 [38400/45000 (85%)]    Loss: 0.500329     LR: 0.000448
Validation set: Avg. loss: 0.5348, Accuracy: 4076/5000 (81.52%)

Epoch 12/30 completed in 30.66s
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Train Loss: 0.4817 - Train Acc: 84.19%
Val Loss: 0.5348 - Val Acc: 81.52%
Best Val Acc: 81.52% (Epoch 12)
Learning Rate: 0.000397
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Train Epoch: 13 [0/45000 (0%)]      Loss: 0.456125      LR: 0.000397
Train Epoch: 13 [12800/45000 (28%)]     Loss: 0.425206      LR: 0.000397
Train Epoch: 13 [25600/45000 (57%)]     Loss: 0.588104      LR: 0.000397
Train Epoch: 13 [38400/45000 (85%)]     Loss: 0.432713      LR: 0.000397
Validation set: Avg. loss: 0.5095, Accuracy: 4151/5000 (83.02%)

Epoch 13/30 completed in 30.41s
Train Loss: 0.4580 - Train Acc: 84.80%
Val Loss: 0.5095 - Val Acc: 83.02%
Best Val Acc: 83.02% (Epoch 13)
Learning Rate: 0.000346
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Train Epoch: 14 [0/45000 (0%)]      Loss: 0.399455      LR: 0.000346
Train Epoch: 14 [12800/45000 (28%)]     Loss: 0.462943      LR: 0.000346
Train Epoch: 14 [25600/45000 (57%)]     Loss: 0.465912      LR: 0.000346
Train Epoch: 14 [38400/45000 (85%)]     Loss: 0.492774      LR: 0.000346
Validation set: Avg. loss: 0.4773, Accuracy: 4175/5000 (83.50%)

Epoch 14/30 completed in 30.06s
Train Loss: 0.4448 - Train Acc: 85.20%
Val Loss: 0.4773 - Val Acc: 83.50%
Best Val Acc: 83.50% (Epoch 14)
Learning Rate: 0.000297
-----------------------------------------------------------------------

Train Epoch: 15 [0/45000 (0%)]      Loss: 0.436327      LR: 0.000297
Train Epoch: 15 [12800/45000 (28%)]     Loss: 0.381425      LR: 0.000297
Train Epoch: 15 [25600/45000 (57%)]     Loss: 0.468561      LR: 0.000297
Train Epoch: 15 [38400/45000 (85%)]     Loss: 0.441446      LR: 0.000297
Validation set: Avg. loss: 0.4917, Accuracy: 4151/5000 (83.02%)

Epoch 15/30 completed in 32.18s
Train Loss: 0.4235 - Train Acc: 85.89%
Val Loss: 0.4917 - Val Acc: 83.02%
Best Val Acc: 83.50% (Epoch 14)
Learning Rate: 0.000251
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Train Epoch: 16 [0/45000 (0%)]      Loss: 0.477953      LR: 0.000251
Train Epoch: 16 [12800/45000 (28%)]     Loss: 0.379713      LR: 0.000251
Train Epoch: 16 [25600/45000 (57%)]     Loss: 0.343391      LR: 0.000251
Train Epoch: 16 [38400/45000 (85%)]     Loss: 0.305635      LR: 0.000251
Validation set: Avg. loss: 0.4666, Accuracy: 4197/5000 (83.94%)

Epoch 16/30 completed in 30.18s
Train Loss: 0.4044 - Train Acc: 86.68%
Val Loss: 0.4666 - Val Acc: 83.94%
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Best Val Acc: 83.94% (Epoch 16)
Learning Rate: 0.000207
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Train Epoch: 17 [0/45000 (0%)]    Loss: 0.399950      LR: 0.000207
Train Epoch: 17 [12800/45000 (28%)]     Loss: 0.401520      LR: 0.000207
Train Epoch: 17 [25600/45000 (57%)]     Loss: 0.320164      LR: 0.000207
Train Epoch: 17 [38400/45000 (85%)]     Loss: 0.474556      LR: 0.000207
Validation set: Avg. loss: 0.4587, Accuracy: 4196/5000 (83.92%)

Epoch 17/30 completed in 29.93s
Train Loss: 0.3823 - Train Acc: 87.41%
Val Loss: 0.4587 - Val Acc: 83.92%
Best Val Acc: 83.94% (Epoch 16)
Learning Rate: 0.000166
----------------------------------------------------------------------


Train Epoch: 18 [0/45000 (0%)]    Loss: 0.315250      LR: 0.000166
Train Epoch: 18 [12800/45000 (28%)]     Loss: 0.354989      LR: 0.000166
Train Epoch: 18 [25600/45000 (57%)]     Loss: 0.312306      LR: 0.000166
Train Epoch: 18 [38400/45000 (85%)]     Loss: 0.387688      LR: 0.000166
Validation set: Avg. loss: 0.4276, Accuracy: 4276/5000 (85.52%)

Epoch 18/30 completed in 31.20s
Train Loss: 0.3620 - Train Acc: 88.18%
Val Loss: 0.4276 - Val Acc: 85.52%
Best Val Acc: 85.52% (Epoch 18)
Learning Rate: 0.000129
----------------------------------------------------------------------


Train Epoch: 19 [0/45000 (0%)]    Loss: 0.318496      LR: 0.000129
Train Epoch: 19 [12800/45000 (28%)]     Loss: 0.406239      LR: 0.000129
Train Epoch: 19 [25600/45000 (57%)]     Loss: 0.373094      LR: 0.000129
Train Epoch: 19 [38400/45000 (85%)]     Loss: 0.389718      LR: 0.000129
Validation set: Avg. loss: 0.4269, Accuracy: 4264/5000 (85.28%)

Epoch 19/30 completed in 29.87s
Train Loss: 0.3440 - Train Acc: 88.95%
Val Loss: 0.4269 - Val Acc: 85.28%
Best Val Acc: 85.52% (Epoch 18)
Learning Rate: 0.000096
----------------------------------------------------------------------


Train Epoch: 20 [0/45000 (0%)]    Loss: 0.285366      LR: 0.000096
Train Epoch: 20 [12800/45000 (28%)]     Loss: 0.348814      LR: 0.000096
Train Epoch: 20 [25600/45000 (57%)]     Loss: 0.363671      LR: 0.000096
Train Epoch: 20 [38400/45000 (85%)]     Loss: 0.341904      LR: 0.000096
Validation set: Avg. loss: 0.4059, Accuracy: 4331/5000 (86.62%)

Epoch 20/30 completed in 30.15s
Train Loss: 0.3281 - Train Acc: 89.44%
Val Loss: 0.4059 - Val Acc: 86.62%
Best Val Acc: 86.62% (Epoch 20)
Learning Rate: 0.000068
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Train Epoch: 21 [0/45000 (0%)]      Loss: 0.357956        LR: 0.000068
Train Epoch: 21 [12800/45000 (28%)]      Loss: 0.341615      LR: 0.000068
Train Epoch: 21 [25600/45000 (57%)]      Loss: 0.290511      LR: 0.000068
Train Epoch: 21 [38400/45000 (85%)]      Loss: 0.328902      LR: 0.000068
Validation set: Avg. loss: 0.3937, Accuracy: 4341/5000 (86.82%)

Epoch 21/30 completed in 32.13s
Train Loss: 0.3100 - Train Acc: 89.94%
Val Loss: 0.3937 - Val Acc: 86.82%
Best Val Acc: 86.82% (Epoch 21)
Learning Rate: 0.000044
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Train Epoch: 22 [0/45000 (0%)]      Loss: 0.244623        LR: 0.000044
Train Epoch: 22 [12800/45000 (28%)]      Loss: 0.307742      LR: 0.000044
Train Epoch: 22 [25600/45000 (57%)]      Loss: 0.266128      LR: 0.000044
Train Epoch: 22 [38400/45000 (85%)]      Loss: 0.310717      LR: 0.000044
Validation set: Avg. loss: 0.3960, Accuracy: 4330/5000 (86.60%)

Epoch 22/30 completed in 29.89s
Train Loss: 0.2984 - Train Acc: 90.49%
Val Loss: 0.3960 - Val Acc: 86.60%
Best Val Acc: 86.82% (Epoch 21)
Learning Rate: 0.000025
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Train Epoch: 23 [0/45000 (0%)]      Loss: 0.300319        LR: 0.000025
Train Epoch: 23 [12800/45000 (28%)]      Loss: 0.319285      LR: 0.000025
Train Epoch: 23 [25600/45000 (57%)]      Loss: 0.237310      LR: 0.000025
Train Epoch: 23 [38400/45000 (85%)]      Loss: 0.391342      LR: 0.000025
Validation set: Avg. loss: 0.3911, Accuracy: 4338/5000 (86.76%)

Epoch 23/30 completed in 29.99s
Train Loss: 0.2884 - Train Acc: 90.72%
Val Loss: 0.3911 - Val Acc: 86.76%
Best Val Acc: 86.82% (Epoch 21)
Learning Rate: 0.000012
------------------------------------------------------------------------

Train Epoch: 24 [0/45000 (0%)]      Loss: 0.369303        LR: 0.000012
Train Epoch: 24 [12800/45000 (28%)]      Loss: 0.276756      LR: 0.000012
Train Epoch: 24 [25600/45000 (57%)]      Loss: 0.253750      LR: 0.000012
Train Epoch: 24 [38400/45000 (85%)]      Loss: 0.209038      LR: 0.000012
Validation set: Avg. loss: 0.3847, Accuracy: 4360/5000 (87.20%)

Epoch 24/30 completed in 30.90s
Train Loss: 0.2786 - Train Acc: 91.25%
Val Loss: 0.3847 - Val Acc: 87.20%
Best Val Acc: 87.20% (Epoch 24)
Learning Rate: 0.000004
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Train Epoch: 25 [0/45000 (0%)]      Loss: 0.344770      LR: 0.000004
Train Epoch: 25 [12800/45000 (28%)]     Loss: 0.320027      LR: 0.000004
Train Epoch: 25 [25600/45000 (57%)]     Loss: 0.325250      LR: 0.000004
Train Epoch: 25 [38400/45000 (85%)]     Loss: 0.269189      LR: 0.000004
Validation set: Avg. loss: 0.3778, Accuracy: 4366/5000 (87.32%)

Epoch 25/30 completed in 29.80s
Train Loss: 0.2790 - Train Acc: 91.07%
Val Loss: 0.3778 - Val Acc: 87.32%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000001
----------------------------------------------------------------------

Train Epoch: 26 [0/45000 (0%)]      Loss: 0.363843      LR: 0.000001
Train Epoch: 26 [12800/45000 (28%)]     Loss: 0.289562      LR: 0.000001
Train Epoch: 26 [25600/45000 (57%)]     Loss: 0.227772      LR: 0.000001
Train Epoch: 26 [38400/45000 (85%)]     Loss: 0.290745      LR: 0.000001
Validation set: Avg. loss: 0.3823, Accuracy: 4358/5000 (87.16%)

Epoch 26/30 completed in 30.35s
Train Loss: 0.2735 - Train Acc: 91.28%
Val Loss: 0.3823 - Val Acc: 87.16%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000004
----------------------------------------------------------------------

Train Epoch: 27 [0/45000 (0%)]      Loss: 0.221195      LR: 0.000004
Train Epoch: 27 [12800/45000 (28%)]     Loss: 0.382206      LR: 0.000004
Train Epoch: 27 [25600/45000 (57%)]     Loss: 0.258080      LR: 0.000004
Train Epoch: 27 [38400/45000 (85%)]     Loss: 0.302770      LR: 0.000004
Validation set: Avg. loss: 0.3845, Accuracy: 4341/5000 (86.82%)

Epoch 27/30 completed in 30.82s
Train Loss: 0.2775 - Train Acc: 91.26%
Val Loss: 0.3845 - Val Acc: 86.82%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000012
----------------------------------------------------------------------

Train Epoch: 28 [0/45000 (0%)]      Loss: 0.291185      LR: 0.000012
Train Epoch: 28 [12800/45000 (28%)]     Loss: 0.236571      LR: 0.000012
Train Epoch: 28 [25600/45000 (57%)]     Loss: 0.206148      LR: 0.000012
Train Epoch: 28 [38400/45000 (85%)]     Loss: 0.269370      LR: 0.000012
Validation set: Avg. loss: 0.3811, Accuracy: 4360/5000 (87.20%)

Epoch 28/30 completed in 31.04s
Train Loss: 0.2804 - Train Acc: 91.18%
Val Loss: 0.3811 - Val Acc: 87.20%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000025
----------------------------------------------------------------------

Train Epoch: 29 [0/45000 (0%)]      Loss: 0.261522      LR: 0.000025
Train Epoch: 29 [12800/45000 (28%)]     Loss: 0.290547      LR: 0.000025
```

```
Train Epoch: 29 [25600/45000 (57%)]      Loss: 0.381201      LR: 0.000025
Train Epoch: 29 [38400/45000 (85%)]      Loss: 0.403549      LR: 0.000025
Validation set: Avg. loss: 0.3884, Accuracy: 4330/5000 (86.60%)

Epoch 29/30 completed in 30.80s
Train Loss: 0.2803 - Train Acc: 91.19%
Val Loss: 0.3884 - Val Acc: 86.60%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000044
------------------------------------------------------------------------

Train Epoch: 30 [0/45000 (0%)]    Loss: 0.238110      LR: 0.000044
Train Epoch: 30 [12800/45000 (28%)]      Loss: 0.378530      LR: 0.000044
Train Epoch: 30 [25600/45000 (57%)]      Loss: 0.312088      LR: 0.000044
Train Epoch: 30 [38400/45000 (85%)]      Loss: 0.296815      LR: 0.000044
Validation set: Avg. loss: 0.4063, Accuracy: 4309/5000 (86.18%)

Epoch 30/30 completed in 29.81s
Train Loss: 0.2831 - Train Acc: 90.90%
Val Loss: 0.4063 - Val Acc: 86.18%
Best Val Acc: 87.32% (Epoch 25)
Learning Rate: 0.000068
------------------------------------------------------------------------

========================================================================
Training Complete!
Total training time: 15.27 minutes
Best validation accuracy: 87.32% at epoch 25
========================================================================

Test set: Avg. loss: 0.3850, Accuracy: 8688/10000 (86.88%)
```
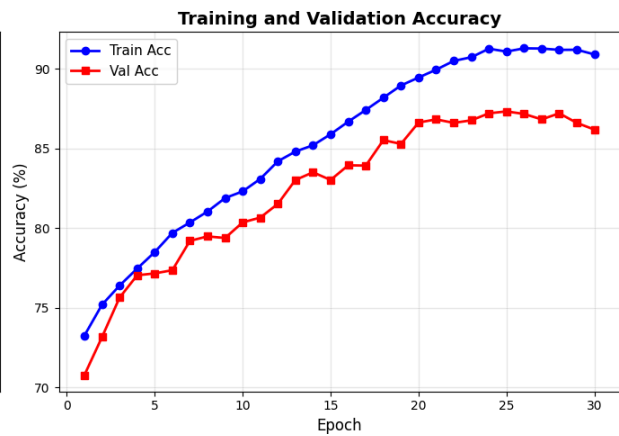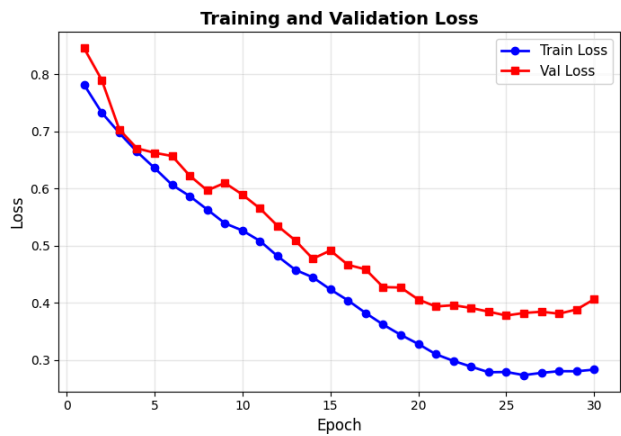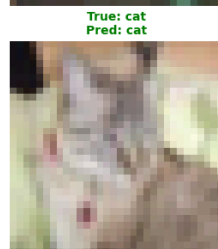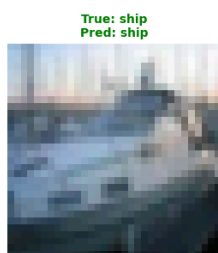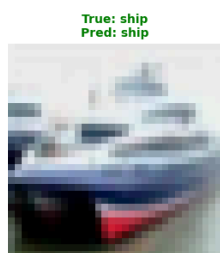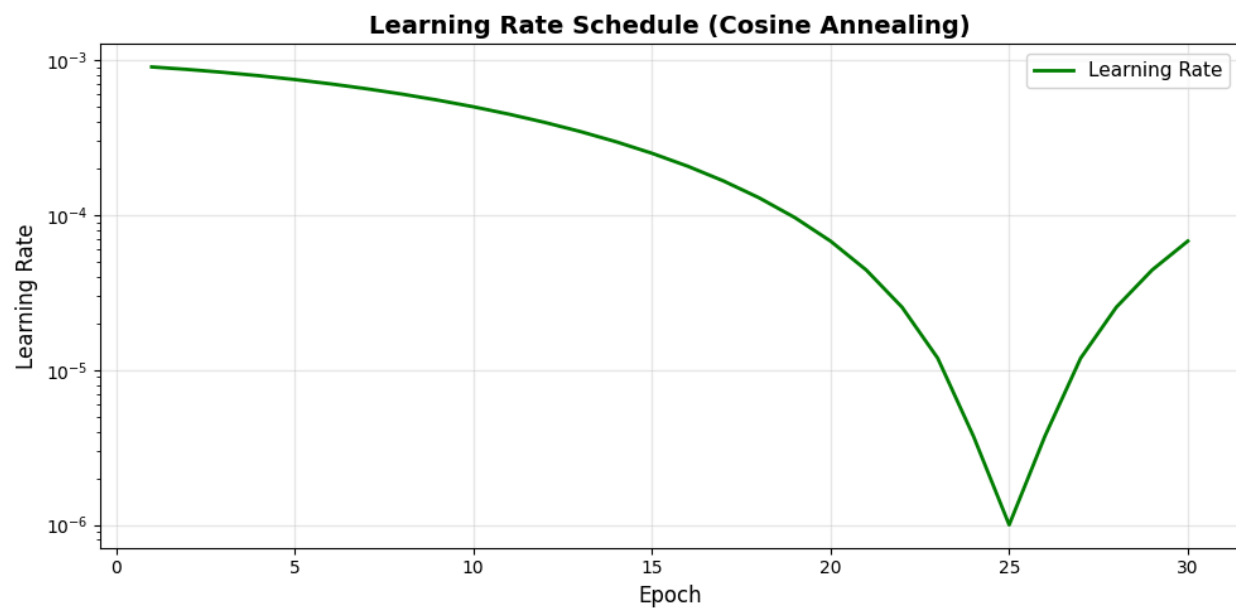

Training and Validation Loss | Training and Validation Accuracy

Learning Rate Schedule (Cosine Annealing)

```
================================================================
FINAL METRICS SUMMARY - PART B
================================================================
Training time: 15.27 minutes (0.25 hours)
Best epoch: 25/30
Best validation accuracy: 87.32%
Final test accuracy: 86.88%
Hyperparameters:
  - Epochs: 30
  - Batch size: 256
  - Learning rate: 0.001 (with Cosine Annealing)
  - Weight decay: 0.0005
  - Dropout: 0.5
================================================================
```

B.3

```
Epoch 1/30, Train Loss: 1.9340, Train Acc: 29.74%, Val Loss: 1.7646, Val Acc: 35.50%
Epoch 2/30, Train Loss: 1.8139, Train Acc: 34.35%, Val Loss: 1.7352, Val Acc: 36.70%
Epoch 3/30, Train Loss: 1.7702, Train Acc: 36.52%, Val Loss: 1.6770, Val Acc: 38.32%
Epoch 4/30, Train Loss: 1.7367, Train Acc: 37.67%, Val Loss: 1.6544, Val Acc: 41.56%
Epoch 5/30, Train Loss: 1.7138, Train Acc: 38.62%, Val Loss: 1.6572, Val Acc: 40.94%
Epoch 6/30, Train Loss: 1.6948, Train Acc: 39.40%, Val Loss: 1.6115, Val Acc: 42.12%
Epoch 7/30, Train Loss: 1.6818, Train Acc: 39.72%, Val Loss: 1.5920, Val Acc: 43.56%
Epoch 8/30, Train Loss: 1.6728, Train Acc: 40.11%, Val Loss: 1.6098, Val Acc: 42.46%
Epoch 9/30, Train Loss: 1.6644, Train Acc: 40.27%, Val Loss: 1.5816, Val Acc: 43.08%
Epoch 10/30, Train Loss: 1.6609, Train Acc: 40.44%, Val Loss: 1.5842, Val Acc: 42.42%
Epoch 11/30, Train Loss: 1.6570, Train Acc: 40.38%, Val Loss: 1.5669, Val Acc: 43.94%
Epoch 12/30, Train Loss: 1.6387, Train Acc: 41.35%, Val Loss: 1.5467, Val Acc: 44.88%
Epoch 13/30, Train Loss: 1.6399, Train Acc: 41.18%, Val Loss: 1.5512, Val Acc: 43.32%
Epoch 14/30, Train Loss: 1.6276, Train Acc: 41.39%, Val Loss: 1.5369, Val Acc: 44.54%
Epoch 15/30, Train Loss: 1.6260, Train Acc: 41.91%, Val Loss: 1.5363, Val Acc: 44.68%
Epoch 16/30, Train Loss: 1.6194, Train Acc: 42.11%, Val Loss: 1.5315, Val Acc: 44.34%
Epoch 17/30, Train Loss: 1.6201, Train Acc: 42.30%, Val Loss: 1.5223, Val Acc: 46.00%
Epoch 18/30, Train Loss: 1.6145, Train Acc: 41.85%, Val Loss: 1.5165, Val Acc: 44.82%
Epoch 19/30, Train Loss: 1.6105, Train Acc: 42.55%, Val Loss: 1.5097, Val Acc: 45.74%
Epoch 20/30, Train Loss: 1.6113, Train Acc: 42.63%, Val Loss: 1.5347, Val Acc: 44.40%
Epoch 21/30, Train Loss: 1.5994, Train Acc: 42.67%, Val Loss: 1.5004, Val Acc: 45.78%
Epoch 22/30, Train Loss: 1.5998, Train Acc: 42.71%, Val Loss: 1.5229, Val Acc: 45.76%
Epoch 23/30, Train Loss: 1.5951, Train Acc: 42.84%, Val Loss: 1.5038, Val Acc: 46.02%
Epoch 24/30, Train Loss: 1.5948, Train Acc: 42.81%, Val Loss: 1.5202, Val Acc: 46.12%
Epoch 25/30, Train Loss: 1.5889, Train Acc: 43.10%, Val Loss: 1.5111, Val Acc: 45.92%
Epoch 26/30, Train Loss: 1.5908, Train Acc: 43.00%, Val Loss: 1.5097, Val Acc: 45.50%
Epoch 27/30, Train Loss: 1.5871, Train Acc: 43.14%, Val Loss: 1.4863, Val Acc: 46.14%
Epoch 28/30, Train Loss: 1.5802, Train Acc: 43.12%, Val Loss: 1.4871, Val Acc: 47.38%
Epoch 29/30, Train Loss: 1.5814, Train Acc: 43.44%, Val Loss: 1.4923, Val Acc: 46.36%
Epoch 30/30, Train Loss: 1.5783, Train Acc: 43.48%, Val Loss: 1.4868, Val Acc: 46.82%
```

Confidence Distribution Comparison: FFNN vs CNN